Periodical

SUPPLEMENT TO THE ENGINEER. MARCH 2, 1934.

PUBLIC LIBRARY
MAR 1 7 1934
DETROIT

The Metallurgist.

Supplement to The Engineer, *March, 1934.*

Publications.

THE amount of scientific and technical matter which appears in the world's publications seems to be increasing continuously, and it already constitutes a serious difficulty. The man who wishes to be up to date in his technical or professional knowledge feels the need of keeping in touch with this immense amount of matter and finds it increasingly difficult to do so. In fact, there are only two courses open to him. One is to read through the abstracts of papers which are published by various societies and journals, and the other is to confine himself to the study of one or two leading publications and only to go beyond these when his attention is called to something of special interest. Neither alternative is satisfactory.

The man who relies upon abstracts has very little opportunity of forming any critical opinion as to the value of the matter contained in the various papers referred to, and he is apt to accept the stated conclusions as reproduced by the abstractor as adequately and well established. He will, of course, come across cases where obvious divergences of facts or opinions become manifest and he will realise that at least one of two differing views must be wrong. What is more likely is that he will fail to realise that a good deal of uncontroverted material is far from being perfectly sound. At the present time an immense amount of material is published as the result of so-called researches carried out by students for the purpose of obtaining a higher degree, and much of this material, although it may furnish useful data and valuable suggestions, is apt to be vitiated by some oversight in regard to the methods used or inadequacy in either the number of measurements, or the materials upon which they are made. This kind of inadequacy can scarcely be detected by examination of abstracts, and it is only the careful reader of the original paper who will form the opinion that too much reliance cannot be placed upon the results or the conclusions drawn from them. Nor is this kind of difficulty entirely confined to the work of junior authors, since there are, unfortunately, a number of men who publish papers upon very insufficient grounds.

This need, for a need it appears to be, of critically sifting the wheat from the chaff in our scientific and technical publications, raises a still greater difficulty in the mind of the reader who wishes to be not only up to date, but as sound in his knowledge as possible. It should be the function of either our technical press or of our great technical and scientific institutions to carry out to some extent the sifting process required, but in actual fact, little or nothing of that sort is attempted. Only a few technical journals, among which THE METALLURGIST may claim to be one of the first, attempt the publication of critical reviews of published work. A particularly interesting development in this direction is presented by reviews which appear in our American contemporary, *Metals and Alloys*, in which a whole group of recent publications relating to a particular subject is summarised and critically discussed. Matter of this kind does not add to the burden of the technical reader, but goes far to lighten it. The great bulk of ordinary abstracts is apt to prove a delusion rather than a help unless it is used as a mere index of contents; for those who pin their faith on statements contained in abstracts alone are apt to build upon an insecure foundation unless the name and status of the author guarantees a certain value to the views expressed and the data published, and of necessity can only apply to a fraction of the new work which appears.

To a very limited extent our great institutions perform a somewhat similar service by the publication of papers together with their discussions. These discussions constitute a feature of very great value, and it is interesting to see that even in Germany this method of publication has been extensively adopted. It may be that in a good many instances a discussion contains little of immediate value or interest, but the very fact that a paper has been read and has been open to discussion at a meeting where a number of eminent specialists are present, does serve as some measure of guarantee that nothing really unreliable or unsatisfactory can have passed through without comment, generally of a highly instructive nature. It might be suggested that a critical refereeing of papers before they are accepted for publication even in an ordinary technical paper might serve the same purpose, but it is a very difficult thing, because one disagrees with the conclusions which an author has drawn, or does not feel entirely satisfied as to the reliability of his results, to go to the length of suppressing his work by refusing it publication. To state one's views plainly at an open meeting during a discussion is a much simpler and wiser course, since it not only gives the author an opportunity to reply so that he can, if he is in a position to do so, substantiate the correctness of his views or data, but it also gives the reader of that discussion, and still more the man who hears it, an opportunity of forming his own judgment as to the opinion which has been expressed of the work, and as to the value both of that work and of that opinion. One might say, therefore, that the reader who confines himself to the journals of our leading institutions would be on safe ground, but, unfortunately, the space at the disposal of these bodies for publication purposes is strictly limited by reason of expense, so that a large mass of important matter has to find publication elsewhere, and this is increasingly the case as the volume of technical and scientific publication increases.

The only conclusion we can draw from these considerations is that, on the one hand, the activities of our Institutions, particularly in the publication of papers which have been discussed, should be supported to the utmost, so that they shall be enabled to deal with as large a number of papers as possible. For the remainder of the published material it seems that careful critical analysis by competent men in the technical press is the best possible course, and we hope that technical journalism may be able to develop in that direction. Such critical treatment, of course, carries with it a high degree of responsibility, since a brilliant, new idea which may strike a reviewer as far-fetched or bizarre may be set back for a number of years by a severe adverse criticism, whereas, on the other hand, a plausible fad may be given a run which it does not in the least deserve. Errors of this kind can only be avoided by care and discretion and the application of a broad outlook which should not readily reject the unknown or accept as gospel whatever may be put forward, even by men of high status. There can be no doubt, however, that critical summarising reviews covering a considerable number of publications on a given subject and appearing at fairly regular intervals, would prove a boon to the anxious reader of technical literature who has to cover an immense field and has not much time in which to cover it.

Research Objectives.

AT a time when the importance of industrial research has achieved a new degree of recognition, it becomes increasingly important that such research should be rightly guided and utilised. It is very easy indeed to expend large sums of money and large amounts of time on work which, while of some interest in itself, leads neither to the development of new scientific facts or ideas nor to the solution of industrial problems. In how far industrial research should concern itself with the actual advancement of knowledge, or with what is sometimes called "pure" research, is to some extent an open question. Many industrialists and many scientific workers regard this as outside the scope of industrial research, but when the scientifically trained technologist attacks the problems of his industry, he is continually finding himself face to face with new facts for which no explanation is available and with gaps in our knowledge which he must fill before he can make further progress. If he sets himself to such a task he is at the same time carrying out "pure" research, and seeking to solve an immediate problem. Unfortunately, the methods applicable to the two purposes are not in general very similar. The industrial problem is always complicated by a large number of variables, many of which are difficult, if not impossible, to control, while for the purpose of "pure" research it is right and necessary in the experimental work to reduce the number of variables as far as possible, in order that the effect of each may be studied separately. If these scientific methods are applied with a view to a sound and complete solution of the industrial problem, the time and money required to achieve the desired result would be very large. Fortunately, things are not as bad as that because it frequently happens that a happy advance in knowledge made by comparatively simple experimental means opens up a new vista which allows the skilled man to see a possible solution of his problem. It is, perhaps, unfortunate that when this happens the purely scientific side of his work is dropped. Indeed, he may not know that he has been doing any purely scientific work. Provided, however, that the knowledge gained is recorded, together with the facts upon which it is based, it will remain available and become fruitful in later years.

The case we have supposed suggests one method of determining the direction which research shall take, but almost every individual worker will be able to suggest more than one problem which requires elucidating, and it is evident that they cannot all be attacked at the same time, whether in the research laboratories of individual firms or in co-operative laboratories or institutions. The course has sometimes been adopted of asking a large number of industrialists for suggestions, on the ground that the industrialist is likely to know what it is he desires to achieve by research. While this method frequently reveals some outstanding gap in our knowledge, at the same time it often leads to entirely undue importance being given to matters of comparatively minor detail, while the larger questions are pushed on one side as too big to be attacked. Research on minor details may be of value if it is kept within bounds, and not allowed to occupy too large a space, either in the laboratory or in the estimation of the firm or organisation which controls it; unfortunately, sometimes a very minor investigation is regarded as an ample provision, on the part of an organisation, for research. Looked at in one way, to ask the industrialist on what subjects he would suggest that research is needed would be rather like asking patients or the general public to suggest the subjects for medical research. Both bodies know what they desire, but have little or no knowledge of the methods by which it can perhaps be achieved. It is the scientific technologist, in the one case, and the medical expert in the other, who can best see where progress in our knowledge is possible, and would be of practical value, and we should be careful to give these men the greatest weight in guiding the directions in research. Experience has shown more than once that what appears to be the most desirable and profitable investigation may prove comparatively fruitless, whereas work in other directions, undertaken perhaps as a good-humoured concession to the whim of a scientific man, has become extremely fruitful.

The fact must be recognised that none of us, even the most expert, can foretell in what direction, even in the near future, scientific progress is likely to benefit industry or where it will lead it. This does not mean that anything like haphazard investigations should be carried out, but that the greatest possible amount of foresight and knowledge, both in industry and in science, should be brought together in co-operation in order to make our expenditure on industrial research as good an investment as possible.

Oxygen and Oxides in Iron and Steel.

No. II. (*continued from December issue*).

Ericson and Benedicks (*Jernkon. Ann.*, 115, 1931) show that alumina is reduced by carbon at temperatures not exceeding 1700 deg. Cent., thus confirming the results of Meyer. Their work marks an important stage in the study of the method. Their furnace of

the von Seth type is characterised by the fact that the connection to the diffusion pump is relatively wide and short. They are the first to employ this type of connection, but do not describe its effects. They employ a degassing temperature of 1700 deg., and a mean reduction temperature of 1550 deg. Cent. The corrections are very small from 0·15 to 0·04 cubic centimetres of carbon monoxide in 15 min. They obtained a reduction of 92 per cent. for alumina in the absence of iron at 1700 deg. Cent. The use of a graphite filter has little influence with samples containing up to 0·05 per cent. of oxygen, but for 0·10 per cent. a recovery of 10 per cent. more gas is obtained. The maximum contents for manganese and aluminium are given as 3 and 2 per cent. respectively, much higher than those given by other authors.

Meyer and Castro (*Arch. Eisenh.*, 6, 1932–33) continued the researches of Diergarten, and of Eilender and Diergarten, with the carbon spiral furnace. They improved the vacuum corrections by increasing the degassing temperature. They used a carbon and copper top which enabled a temperature of 2000 deg. Cent. to be reached, and a blank of the order of 0·2 cubic centimetres of CO in 15 min. at 1660 deg. Cent. By increasing the diameter of the connecting tubes to the pump from 8 mm. to 25 mm., they effected a more rapid and complete evacuation of the furnace gases. They note that von Seth working with a simple mercury pump (delivery about 1 cubic centimetre per second) did not get reliable results. Vacher and Jordan with long and narrow connections and a small pump are hindered by 0·24 per cent. manganese. At the other extreme, Ericson and Benedicks, with short and relatively wide connections, indicate 3 per cent. manganese as the limit. The value of 0·6 per cent. manganese by Eilender and Diergarten and 1·0 per cent. by Bardenheuer and Schneider correspond to intermediate diameters of the connections. It would appear therefore that the maximum permissible content of manganese and aluminium depends on the suction speed of the gases. Meyer and Castro also replaced the carbon cylinder screen by a screen of pure molybdenum sheet, and as a result of the modifications attained a degassing temperature of 2200 deg. Cent., reduced the time for degassing, and obtained blanks of 0·015 to 0·02 cubic centimetres of CO in 15 min. at 1720 deg. Cent. These quantities of carbon monoxide correspond to corrections of the oxygen value of 0·00015 to 0·0002 per cent. for 12-gramme samples and a duration of the analysis of 30 min. They also replaced the costly and complicated Beutell pump with a pump of simpler type.

The advantages of the high-frequency type of furnace are its extreme simplicity and the small quantity of carbon which it contains. It is easy to dismantle and clean, and both nitrogen and hydrogen can be estimated at the same time as the oxygen. The vigorous agitation of the liquid metal bath assists the reaction. On the other hand, it is costly and the generator is complicated and the temperature difficult to control. The introduction of each sample necessitates a readjustment. Also the difficulty of degassing above 1750 deg. Cent. leads to higher blank values.

The carbon spiral furnace is cheaper and easier to control. It is easily constructed and very robust, with the exception of the spiral. The fact that degassing can be carried out at 2200 deg. Cent. allows very small vacuum corrections. The inconveniences are the very great interior complication and the large amount of graphite, which prolongs the degassing time for a new furnace. The spirals are very fragile, but it is possible to effect improvements in this respect. The time for the reduction of a sample is a little greater than in the other furnace on account of the lack of movement of the liquid metal.

This type of method is still only suitable for research laboratories, but further study may eventually produce a simpler apparatus suitable for use in any well-equipped industrial laboratory.

Herty and his co-workers have developed a method which depends on the formation of alumina when aluminium is added to a sample of molten steel. The equilibrium of deoxidation is such that an addition of 1 per cent. of aluminium is sufficient to reduce the concentration of FeO to 0·008 per cent., equivalent to 0·0018 per cent. of oxygen. The quantity of alumina formed is estimated by a " residue " method. Oxide of manganese and silica are not recovered by this method.

Residue methods of analysis have received a great deal of attention. Volatilisation in a current of chlorine is a very old type. Recent work indicates that the chlorine must be as pure as possible. Silica may be reduced in contact with any carbon present. Oxides of manganese and iron may also be partially decomposed. The reaction may raise the temperature considerably above that of the furnace. Mixing the chlorine with nitrogen reduces this difficulty. Very fine particles in the steel are probably most reactive, and such particles may be lost unless an ultra filter of cellulose is employed. According to Portevin and Castro, silica and alumina can be determined with reasonable accuracy.

The bromine method also necessitates the use of ultra filters, and it does not appear to possess any advantages over chlorine. It is disagreeable and even dangerous, and is now very little used.

The iodine method is more promising. Willems uses a saturated solution of iodine in absolute alcohol and special nitro-cellulose filters (*Arch. Eisenh.*, 1, 1927–28). He also filters the iodine solution through a similar filter before introducing the sample. The estimation of silica and alumina yields results in agreement with those by other methods. Traces of moisture exert a very great influence on the recovery of oxides of iron and manganese. Absolute alcohol is very hygroscopic and may absorb moisture during handling. Kinzel and Crafts (*Tech. Pub.* A.I.M.M.E., Nos. 402 (1930), 436 (1931)), use a cold solution of ferric iodide containing ammonium citrate to avoid the formation of insoluble basic salts. More experience is necessary with this method before a definite opinion can be given as to its applicability.

Methods of solution in dilute hydrochloric acid have the advantage of cheapness and ease of manipulation. They are stated to be reliable for the estimation of silica and alumina. Solution in nitric acid, a method devised by Stead and perfected by Dickenson (*J.*, Iron and Steel Inst., 113, 1926) is claimed to recover all the silicates. The value of the method is, however, contested by other workers. It is rather lengthy and may occupy from ten days to six weeks, according to the weight of the sample and the type of steel.

The use of saline solutions is practically only of historical interest. Willem's method alone appears to be of some interest. He applies it for the determination of silica and alumina. The sample is dissolved in an excess of a solution of copper ammonium chloride in an atmosphere of nitrogen. Results are in excellent agreement with those by the iodine method.

Electrolytic methods have been studied by Herty and his co-workers (*Min. Met. Invest. Coop. Bull.*, No. 37 (1928), No. 44 (1930)). One difficulty encountered is the contamination of the residue by hydroxides of iron. Another is that although the solution may be neutral at the beginning of the reaction, it soon becomes sufficiently acid to attack the more soluble constituents of the slag and oxide residue. Fitterer (*Tech. Pub.*, A.I.M.M.E., No. 440 (1931)), encloses the steel sample in a covering of collodion, and uses a neutral electrolyte. The residue is retained in the collodion envelope. The electrolyte consists of 3 per cent. ferrous sulphate and 1 per cent. sodium chloride neutralised by a blank electrolysis for two to three hours. After electrolysing for twenty-four hours the partially dissolved sample is removed and weighed and the residue in the collodion envelope recovered on a filter. The estimation of ferrous oxide is impossible owing to the formation of hydroxide. The presence of silicate of manganese renders the separation of the oxide and sulphide impossible.

Scott (*Ind. Eng. Chem.*, 1931, 1, pages 121–25), uses a slightly iodised solution of magnesium iodide as the electrolyte which prevents the formation of ferric hydroxide. The electrodes are separated by means of hardened filter paper. With carbon steels some metallic particles are carried away by the separation of the carbon. The residue is treated therefore with a dilute solution of iodine in alcohol for twenty-four hours with occasional shaking. In extreme cases the major portion of the iron contained in the residue is derived from these particles and the estimation of ferrous oxide is impossible. Corrections have also to be made in the case of oxide of manganese and silica. Scott's process requires fewer precautions than that of Fitterer. According to the author, sulphur, phosphorus, and carbon compounds are decomposed.

Treje and Benedicks (*Jernk. Ann.*, 116, 1932) adopt as the anode electrolyte a decinormal solution of potassium bromide with the addition of 10 per cent. sodium citrate and for the cathode a 10 per cent. solution of copper sulphate. The cathode is surrounded by a porous clay cell. Micrographical methods of control are adopted which are only qualitative. The residues from high-carbon steels are contaminated by carbides which are separated by a magnetic method. The experiments are being continued, and may result in important progress.

Micrographical methods of examination yield information of a qualitative character on the nature of the inclusions. These methods usually consist in the examination of polished sections after treatment with various reagents. The principal difficulties are due to the complexity of composition of the inclusions which tends to reduce the selectivity of particular reagents. The small size and difficulty of polishing certain inclusions is also a drawback. Examination by ultra-violet and polarised light is of great assistance in identifying inclusions.

The above methods have also been applied for the examination of the products obtained by residue methods of analysis.

Another micrographic method consists in determining the number of inclusions per unit of area. Size and aspect are also taken into account. This method is long and tedious and subject to many errors.

Cementation under standardised conditions followed by micrographic examination has also been proposed as a quantitative method for determining the degree of oxidation of a steel.

Portevin and Castro conclude that it is possible at the present time to estimate the total oxygen with an error of less than 0·001 per cent. in steels and cast irons containing less than 2 to 3 per cent. of manganese and 1 to 2 per cent. of aluminium. They also regard as doubtful all results and conclusions obtained prior to the last three years. The determination of oxygen is classed among the most delicate analyses of present-day chemistry. It is slow and can only be confided to skilled and experienced workers.

This summary by Portevin and Castro is an important contribution to the study of methods for the determination of oxygen in iron and steel, and should be of very great service to workers in this field. Criticism is difficult, but it may be interesting to observe how far the authors' conclusions are justified with regard to particular methods. The electrolytic residue method, for example, may still be regarded as merely in the experimental stage, and problems connected with the separation of carbides may be difficult to solve in a quantitative manner. The iodine method appears to the reviewer to offer more scope for investigation, and is preferable to the chlorine method. The difficulty here is also due to refractory carbides. The decomposition of sulphides and similar compounds by the iodine is also a drawback.

Materials for Chemical Plant.

(*From a Correspondent.*)

THE rapid expansion of the chemical industries in practically every direction, the development of new ones, and the increasing application of chemistry in several industries, old and new, such as wireless, for instance, has involved a corresponding demand for materials for chemical plant. Among these, metals, both ferrous and non-ferrous, have played and are playing an important part, especially in the form of alloys resistant to chemical conditions of the most drastic kind, including high temperatures and pressures and exposure to acidic and alkaline corrosion. Probably the most severe strain of all is not so much the steady application of high temperature or pressure as sudden changes in these conditions. Until recently metals and their ancient rival, stoneware or other ceramic material, almost monopolised the whole field, and the remarkable advances in metallurgy and the production of an ever-increasing and bewildering variety of alloys have enabled the metals to retain by far the larger share of this field; but during the past year or two a rather formidable rival has appeared in the form of plastic materials of various kinds. Among these a preliminary note may be made of Haveg, a phenolic resinoid, which, *inter alia*, is highly resistant to rapid changes in temperature—a very valuable quality under modern conditions. There is also Transite, a mixture of asbestos and Portland cement, for which high claims are made. Further, a new kind of stoneware has been introduced which is said to be much less fragile owing to removal of gases from the clay during manufacture. It therefore behoves manufacturers of metallic alloys and metallurgists generally to watch these various new developments. And in this connection it should not be forgotten that even wood is by no means an anachronism in modern chemical plant. There are to-day so many methods of treating timber, so many ways of protecting it by paints, &c., coating it with rubber, asbestos, bitumin-

ous or other material, and so forth, that it has not only retained its position as a highly valuable material for chemical plant, but bids fair to extend its usefulness and applications still further.

During the last year or two lists have been published, both in this country and the U.S.A., showing the wide range of different materials used in the chemical industries. One such list, published in *Jnl., Ind. and Eng. Chem.*, 1932, and based on questionnaires to chemical manufacturers, contained fifty-five metallic materials and fifteen non-metallic. Another list which appeared in *Chem. Met. Eng.*, also in 1932, and based on information from makers of these materials, contained no less than 258 metallic and eighty-two non-metallic materials. As W. R. Huey points out, in a further article on the same subject (*J. Ind. Eng. Chem.*, 1934, January), it is evident that there are numerous materials unknown or insufficiently appreciated by users, but the latter have necessarily adopted a rather cautious and even incredulous attitude towards the many "new" alloys, &c., and the high claims which have not always been substantiated. But, despite exaggeration here and there, very real and considerable progress has been made; so much so indeed that many important chemical operations would be almost impossible without the aid thus given by the metallurgist.

Among the more important of these aids in the metallic class are alloy-clad steel, beryllium alloys, chromium steel, and the various types of stainless alloys. Attempts at bonding thin sheets of alloy to steel go back many years, and many difficulties have been encountered. Satisfactory results have, however, been achieved with chromium-nickel sheets, bonded by spot welding with approximately 144 spots per square foot. Another method is to weld together slabs of alloy and carbon steel and obtain a homogeneous continuous weld in the usual rolling operations. The alloy sheet may be bonded to one surface or to both. These operations demand great skill and care, as weak or thin spots may easily be left in the layer of alloy, especially after rolling. The method is not recommended where the thickness of metal does not exceed $\frac{3}{8}$in.

The remarkable increase in strength and hardness obtained by addition of small percentages of beryllium to copper is now well known. Silicon, too, has played an important part in recent alloy research. The high-silicon iron group includes such valuable alloys as Duriron, Corrosiron, and Tantiron, which are more resistant to a large variety of compounds than any other moderately priced alloys. Unless, however, a certain amount of molybdenum (up to 4 per cent.) is present they are liable to attack by hot concentrated solutions of hydrochloric acid. One form of this molybdenum alloy is known as Durichlor, which is also strongly resistant to sulphuric acid. These materials are, however, rather brittle, and can only be obtained as castings. They cannot, as a rule, be easily machined, and must be shaped and finished by grinding. Chromium steel, another valuable material for chemical plant, may contain up to 7 per cent. chromium, together with 0·25 per cent. molybdenum. By annealing and properly controlled heat treatment, and by adjusting the carbon and chromium content, a wide range of physical properties can be obtained. The corrosion resistance under various conditions is from two to nine times as high as that of ordinary carbon steel. In the stainless alloys in which titanium, tungsten, molybdenum, and silicon are used, interesting improvements have lately been made by small additions of zirconium or selenium, or an inert gas like nitrogen. Among the single metals, silver, owing to its present comparatively low price, is finding increased use in several ways; and the same applies to tantalum, especially in the food and pharmaceutical industries. As is well known, silver is highly resistant to many acids and also to the halogen gases—chlorine, bromine, &c. Considerable progress has been made in the use of tantalum, despite such difficulties as high melting point, gas absorption, and rapid oxidation at high temperatures.

Among the non-metallic materials, leaving out of account the many kinds of new stoneware and treated timber, probably the most important developments are in the plastic field, such, for example, as the phenolic resinoids of the Haveg type. This part of the subject is, however, too large and important to be adequately dealt with here. Other interesting materials are natural and synthetic rubbers of various kinds; mixtures of asbestos with Portland cement, *e.g.*, Transite; armoured silica, non-metallic coatings of various kinds on wood or metal, of an asphaltic or bituminous nature; various kinds of paints, such as the recently introduced "Houghto-Kote," &c.

Both in the metallic and non-metallic field the aim is to acquire such chemical and metallurgical knowledge that materials of any desired specification may be compounded, as in new flotation chemicals, resins, and insulating materials; or high-strength castings, new bearing metals, and so forth. The number of new compounds introduced in the plastics and alloy manufacturing industries is already enormous. Over 3500 alloys are listed in Cassier's "Metal Handbook," yet it still seems as difficult as ever to predict what will be the precise qualities of any new combination of metals or metals and non-metals. Possibly the greatest assistance will be derived from the comparatively new science of "Surface Chemistry," as developed by Dr. Irving Langmuir (*Chem. Reviews*, U.S.A., October, 1933) and others, and the more intensive application of so-called indirect methods, ultra-violet light, measurement by microns, timing in microseconds, and the marvellous electronic devices invented in the last year or two. Langmuir found that films of oil on water, of oxygen and thorium on tungsten, and numerous other combinations behave like two-dimensional substances having gaseous, liquid, or even solid characteristics, owing to common orientation of their molecules resulting from their chemical affinity for, and their insolubility in, the underlying material. The films on metals have a crystalline character owing to the space lattice of the metal structure. Evaporation of gases from metal, action of catalysts in chemical reaction, and the wetting of one material by another have been shown to be controlled by varying magnitudes and the polar character of the attractive forces between dissimilar molecules. The knowledge so gained has proved of great value in many fields, such as lubrication, vacuum tubes (wireless valves, &c.), and especially in the flotation of ores. But the new science of surface chemistry will not stop at these, and is bound to exercise a profound effect on the surface treatment of metals and on metallurgy generally. This is yet another brilliant example, indicating to what far-reaching and valuable applications research in pure science may lead.

In regard to future developments in chemical plant materials it may still be said that, despite the great progress made in recent years, the perfect alloy or material for the manufacturer of such plant has not yet been produced. Chemical industry still awaits the appearance of the alloy which is completely immune to corrosive attack and applicable to all

types of equipment. Progress in this direction is rendered more difficult owing to the fact that there are comparatively few metals available for use in commercial quantities, and the possible combinations of these have been fairly well tested. There seems to be a wider field for research in the non-metallic group, stoneware, plastics, and possibly combinations of these latter with metal; also in reducing cost of existing materials. If larger supplies of what are at present called rare metals could be discovered so that they were no longer rare, both the ferrous and non-ferrous metallurgist could look forward with brighter hopes to commercially successful results. There thus seems to be plenty of scope for the economic geologist and mineral prospector, for it is fairly safe to say that there are in various parts of the world vast mineral resources still undiscovered. It is in any event certain that, with the present rate of consumption of many of the metals, and the prospects of a large acceleration in that rate, there will soon be a shortage, and the question of reasonable conservation, in the absence of fresh supplies, will become paramount.

Austenitic Chrome-Nickel Steels.*

SINCE the introduction of this class of stainless steels much investigatory work has been carried out in this country and abroad on their physical and chemical characteristics, and numerous special features, originally unsuspected, have been brought to light. The phenomenon of intercrystalline corrosion in this class of steels is now well known and its main features are well appreciated and have been discussed at length in various publications. Hot brittleness, which is frequently considered to be an associated phenomenon, whilst of a less pronounced and insidious character, has also been well explored and discussed. The article by the two authors mentioned, which appeared in a recent issue of the German publication on corrosion, gives a general survey of present knowledge and introduces an account of some experimental work by the authors.

The steels surveyed are of the usual range for the chrome-nickel austenitic stainless type, having chromium contents of 12–20 per cent. or higher if used for heat-resisting purposes, 7–20 per cent. of nickel or higher, with additions of other elements, for special purposes. In the case of the corrosion-resisting steels the carbon content is usually not above 0·2 per cent., but higher values are employed for special purposes.

Whilst these steels usually have substantial ductility at ordinary temperatures, and have, in fact, extreme toughness as a special characteristic, tensile tests taken at gradually increasing temperatures show definite reduction of ductility in the zone of 600 deg. to 900 deg. Cent., in spite of the fact that the tensile strength in this zone is also very much reduced. This feature is that referred to by the authors as "hot brittleness." A graph is given in the article illustrating results obtained with tensile tests on an 18/8 chrome-nickel steel containing 0·1 per cent. carbon, in which the "pull" occupied a period of thirty minutes. For this sample an elongation of 60 per cent. at ordinary temperatures is seen to fall at 900 deg. Cent. to about 14 per cent., after which there is a rise.

* M. Schmidt and O. Jungwirth. "Korrosion und Metallschutz," November, 1933, Vol. 9, No. 11, pp. 293–302.

Further tests by the authors investigate the effect of carbon percentage on this property. Samples of 18/8 steels having carbon varying from 0·02 to 0·41 per cent., tested in the condition as quenched from 1000 deg. Cent., each gave a minimum elongation at 850 deg. Cent., with a falling-off as compared with ordinary temperature tests of the same order. For example, the 0·02 per cent. carbon steel fell from 50 per cent. to 10·5 per cent. (on $l=1·5\,d$) and the 0·41 per cent. carbon steel fell from 41 per cent. to about 6 per cent.

This reproduction of the phenomenon to a similar order with the high as with the low carbon content does not support the theory that the hot shortness is due to "precipitated carbides." The authors quote data in which it is seen that other types of austenitic steels exhibit the same property, including nickel-chrome-tungsten steels, 25 per cent. nickel steel, 14 per cent. manganese steel (all as water quenched from 1100 deg. to 1150 deg. Cent.), and a semi-austenitic chrome-nickel steel of 18/5·5 composition, which had been tempered at 750 deg. Cent. A steel containing 22·5 per cent. chromium and 18·7 per cent. nickel showed a relatively small loss of ductility of from 45 per cent. to 23 per cent. elongation, the latter value being obtained at 980 deg. Cent.

Some similar brittleness is shown by some ferritic and pearlitic steels, such as hyper-eutectic rail steel and Armco iron.

In the austenitic steels mentioned above long periods of heating in the embrittling range produces some modification in the properties obtained by subsequently testing at room temperatures, but the amount of such reduction is relatively small—*e.g.*, an 18/8 steel only dropped from 50 per cent. to 49 per cent. elongation after 400 hours at 800 deg. Cent., although the hot test at 800 deg. Cent. gave only 15 per cent. elongation. The breaking strength increased slightly as a result of the exposure. The fracture of a hot-short sample is seen to be mainly intercrystalline, with very little deformation of the crystallites, whilst the same material, pulled cold, showed substantial deformation of the crystals.

The question of relative strength of crystals and crystal boundaries and its variation with temperature is discussed, and a suggestive diagram, due to Stäger and Zschokke, showing the crossing over of these relative strengths for certain temperatures, is reproduced. It may, however, be pointed out that a very similar diagram, which is applicable to all metals and alloys in the same temperature range, was given—and explained—by Rosenhain many years ago. It is stated that the "equi-cohesive" temperature is reduced under conditions of continuous loading, since the softening of the intergranular substance requires time. The upper limit of the brittle range is stated to occur with the commencement of recrystallisation.

Hot forging tests on an austenitic alloy, at temperatures between 1000 deg. Cent. and 600 deg. Cent., after previous heating to 1080 deg. Cent., failed to produce cracking. Tensile tests, made at the temperature at which brittleness was previously found, if made at the same temperatures on a falling heat (previously heated to 1100 deg. Cent.) did not reproduce the brittleness. Rapid speeds of pulling were also found to minimise the brittleness (*e.g.*, a one-minute test gave in one case a 40 per cent. elongation, compared with 18 per cent. for a thirty-minute test), and it is considered that the combination of high initial temperature and rapid deformation account for

the non-reproduction of cracking in the above-mentioned forging tests.

Hot brittleness is considered not to be a serious factor in the forging of this class of steel.

INTERCRYSTALLINE CORROSION.

This type of corrosion occurs when there is breakdown at the crystal boundary whilst the crystals themselves are resistant to the corroding medium. Such a corrosive attack causes brittleness and may lead to complete disintegration of the material to crystalline powder. The authors quote the work of Strauss and others, in which it is shown that an 18/8 chrome-nickel steel, quenched from 1050–1100 deg. Cent. and resistant under the condition, is rendered liable to attack by reheating to a temperature between 500 deg. and 900 deg. Cent., such as occurs during welding in the material adjacent to the weld. The change in structure which leads to liability to this form of attack is removed by requenching from 1050–1100 deg. Cent. It is considered that the homogeneous water-quenched condition is an unstable one and that the reheating brings about a more stable one by causing precipitation of "carbides held in solution." An illustration of this precipitation of carbides is given, showing their formation at crystal boundaries. The maximum precipitation is considered to occur at 800 deg. Cent. (method of determination not shown, but attributed to Greulich and Bedeschi). Formation of ferrite is considered to occur, this decision being based on magnetic tests and dilatometric measurements. The use of the now well-known method of testing for liability to this form of corrosion by the boiling copper sulphate-sulphuric acid solution is then described.

The theory given for the change in structure leading to liability to intercrystalline attack is that which has been propounded elsewhere, *i.e.*, that the deposition at the boundaries of carbides of chromium leads to impoverishment of the neighbouring material of its chromium, such regions thus being brought below the "passivity limit." The low rate of chromium diffusion is held to account for the persistence of the inequalities thus set up. The formation of "ferrite" at the reheating temperature, it is thought, may also be a factor. Tests done on samples of 18/8 after reheating to various temperatures between 600 deg. and 900 deg. Cent. showed the worst result at 700 deg. Cent.

The rest of the paper deals with the methods adopted for avoiding the liability to intercrystalline corrosion. These are given as :—

(*a*) Decrease of carbon content,
(*b*) Increase of chromium content,
(*c*) Rendering the carbon innocuous by the addition of an alloying element of greater carbon affinity than chromium,
(*d*) By heating to permit diffusion.
(*e*) By heating to permit recrystallisation.

By "magnetic saturation" and "potential" tests reduction of the carbon content to 0·04 per cent. is shown to be effective against the influence of ten minutes' heating at 700 deg. Cent., but with carbon over 0·06 per cent. immunity against the effect of reheating is not obtained. Production of these steels with such low carbon content presents considerable practical difficulties.

The theory of the principle of increasing the chromium content is that the impoverishment in chromium near the boundaries where carbide is precipitated should still leave the chromium sufficiently high for adequate corrosion resistance. This method is not pursued commercially, the reason given by the authors being the reduction in mechanical properties brought about by the higher chromium, or increased cost due to an increase in nickel content necessary to restore satisfactory properties. The added elements in method (*c*) for curing intercrystalline corrosion are : tantalum, titanium, vanadium, tungsten, and silicon. These are stated to form "chemically neutral carbides," the amount of the necessary additions being approximately five to six times the carbon content. An illustration is given of the effectiveness of "tantalum" in this respect on a welded sample and the authors query the effectiveness of silicon or tungsten for the purpose.

Method (*d*) is prolonged heating at 900 deg. Cent. to bring about diffusion of the precipitated carbides. Owing to difficulties regarding differences in casts and a narrow range of suitable temperature, this method is not recommended by the authors.

Method (*e*) is first to cause precipitation of carbides by heating at 600 deg. to 900 deg. Cent., then cold work to about 50 per cent. reduction and finally reheat to 850 deg. Cent. to cause recrystallisation, leaving the carbides in positions away from the grain boundaries. This method is said to be commercially practicable, and cold working is stated not to have any adverse influence on the tendency to intercrystalline corrosion.

By use of the special modifications of corrosion-resisting steels immune to intercrystalline attack, the construction of large vessels and other plant is now carried out safely without the necessity for subsequent heat treatment after the various operations in fabrication.

The article is logically written, although with perhaps too much insistence on the theoretical explanations, which are apt to be too readily accepted as facts. The "chromium impoverishment" theory of intercrystalline corrosion requires further experimental support. The general ideas and data expressed, however, differ little from current views in this country.

One new feature is introduced, *i.e.*, the use of tantalum as a stabiliser for the carbides in the chrome-nickel steels, with a view to rendering them immune against intercrystalline corrosion. Unfortunately, the authors do not indicate up to what range of carbon content the element would be effective. One is tempted to infer that their view is based upon one example, *i.e.*, a steel whose analysis is quoted in their Table I., which is a steel with 19 per cent. chromium, 7·9 per cent. nickel, 1·01 per cent. tantalum, and 0·04 per cent. carbon. If this inference is correct, the evidence regarding the effect of tantalum is nil, if we accept the authors' own evidence as to the effect of carbon. Perhaps more may be heard later on the effect of this element. The use of high molybdenum (4 per cent.) as a stabiliser, which is thought by some authorities to be effective, is not mentioned.

Dendritic Figures in Liquid Films.

AN interesting paper by Toshimasa Tsutsui, "On Dendrite Figures Produced in Liquid Films" (Part 1), has appeared in the "Scientific Papers of the Institute of Physical and Chemical Research," Vol. 22, No. 456.

Dendritic figures may be produced in thin liquid

films by lifting the upper of two horizontal flat plates between which there is, initially, a thin film of viscous liquid. The figures result from the ingress of air at a large number of points on the periphery of the film. By using transparent plates the figures may be photographed by transmitted light during their formation. Alternatively, opaque plates may be used, in which case the liquid must contain a volatile constituent which evaporates and leaves a very viscous or solid residue, and thus "fixes" the pattern. A cellulose enamel proved suitable for this method of observation.

In Mr. Tsutsui's earlier experiments the top plate was rectangular, and hinged at the base, so that the air entered the liquid at points along the opposite edge.

Fig. 1 is a reproduction of one of the author's excellent series of photographs. The black parts of the pictures represent liquid, and the white parts represent air which has entered the liquid from the top edge of the cell. At a certain distance from this edge the structure changes from dendritic to cellular, and the cells diminish in size towards the hinged edge. In Fig. 1 the rate of lifting

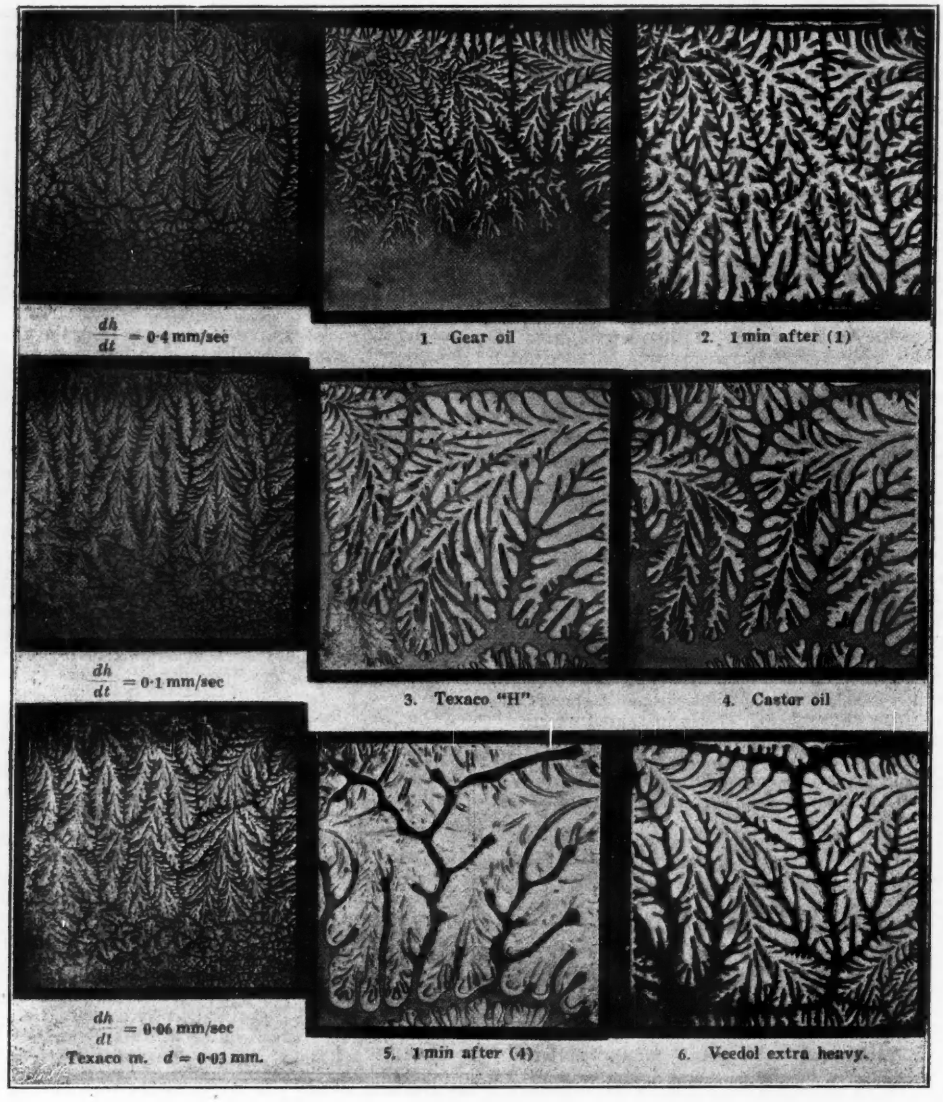
$\frac{dh}{dt}$ = 0·4 mm/sec
1. Gear oil
2. 1 min after (1)
$\frac{dh}{dt}$ = 0·1 mm/sec
3. Texaco "H"
4. Castor oil
$\frac{dh}{dt}$ = 0·06 mm/sec
Texaco m. d = 0·03 mm.
5. 1 min after (4)
6. Veedol extra heavy.

FIG. 1 AND 2

the upper edge of the top plate is denoted by $\frac{dh}{dt}$, the distance between the plates being measured in millimetres, and the time in seconds. An increase in the velocity of separation of the plates causes an increase in the relative area of the cellular part of the structure. Fig. 2 shows some purely dendritic structures obtained at low rates of separation.

Mr. Tsutsui examined quantitatively what we may call the "fineness" of the dendritic structure. For this purpose it was convenient to regard the structure as a branched system of liquid, rather than as a branched system of air passages. A few liquid stems were picked up at the lower part of a figure, and the average number of branches per unit length was obtained. Presumably, the length was the component resolved parallel to the side of the plate, and not the actual length of the stem in question, although the author does not make this clear.

Let the average number of branches per unit length be n, and the initial separation of the plates at the top of the cell be h_o. Then, for a constant velocity of separation equal to $\frac{dh}{dt}$, it was found that

$$n = \frac{\frac{dh}{dt}}{h_o\left(a + b\frac{dh}{dt}\right)}$$

where a and b are constant for a given liquid. These constants have not been correlated exactly with the physical constants of the liquid, but it appears that, other things being equal, the value of n increases with increase of viscosity, so that a, or b, or both of them, decrease with increasing viscosity.

Some experiments were carried out in which the air surrounding the plates was replaced by various liquids. The patterns obtained in these experiments were, in general, more complicated, and exhibited more variety than the earlier ones, their formation being, doubtless, determined by very complex conditions.

Returning to experiments with air as the surrounding medium, observations were made on the cellular structure which occupies the whole rectangle for high velocities of separation. It was found that the cells were largest near the centre of the plates, and also increased in size with increase in the initial separation of the latter.

Further experiments were performed with a different apparatus arranged so that separation of the plates took place along the bottom edge as well as at the top. There was still, however, somewhat greater separation of the plates along the upper edge. The figures observed are of the same general type as the previous ones, but exhibit a radial character owing to the ingress of air from points all along the periphery of the cell.

In these experiments it was found that by using a very viscous liquid, such as vaseline, and a sufficiently low rate of separation, the liquid could be made to flow to the centre without breaking up into either a dendritic or a cellular structure. The experiments were performed with circular instead of rectangular plates, the vaseline flowing radially towards their centre. At a certain radius the vaseline tore away from the plates, leaving only a very thin film, and later, re-adhesion occurred at a smaller radius, an annular space being left almost free from vaseline. The outer radius of the annulus seems to correspond with the existence of a maximum shear stress in the vaseline which cannot be exceeded except in the case of a very thin film.

Very interesting results were obtained by changing the shape of the lower glass plate. The resulting dendritic figures bear a striking similarity to the flow lines produced by twisting metal bars having the same cross-sectional shapes as those of the lower plates. Fig. 3 illustrates this similarity. The dendritic portions of the liquid figure correspond with plastic deformation in the twisted rod, whilst the non-dendritic portions in the liquid figure correspond with elastic deformation in the rod.

The numerous, and very beautiful photographs in the original paper show remarkable resemblances to structures familiar to metallographers, although the detailed causes of the structures are quite different. In a similar way, the structure of a hexagonal, crystalline metal is simulated by the pattern produced by the uniform heating of the under surface of a very thin liquid film, a phenomenon which has been admirably studied by Professor Bénard. A less perfect example is to be seen at the bottom of a dried-up lake, where the drying mud cracks into a polygonal structure in which the hexagon predominates.

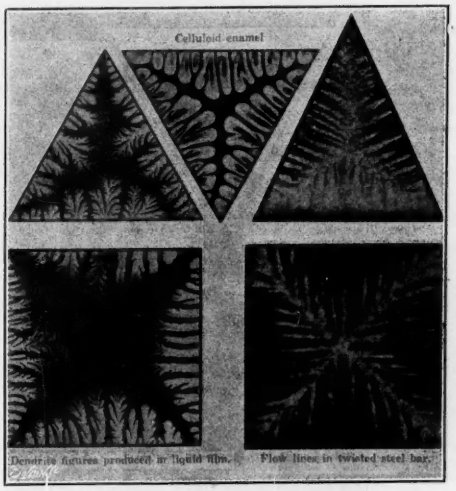

FIG. 3

It is always good to bear in mind that different causes may produce almost indistinguishable effects, a truth which is overlooked more frequently than might be supposed by those who should know better. The curious observations of Mr. Tsutsui are of value, both for their intrinsic interest, and because they afford an excellent example of the above proposition.

Gongs.

No. I.

CONSIDERING the antiquity of the art of making gongs and bells, there is a surprisingly small amount of information available regarding the factors affecting the characteristics of the sound which they are

capable of emitting. Anton Pomp and Burghard Zapp in a recent publication* have remedied this omission in a very thorough manner in relation to one specialised application. The case which they have investigated in remarkable detail is that of the gongs used in the chiming mechanism of mantel clocks.

The gongs under consideration are made from steel wire, and are generally 40 cm. to 70 cm. long and about 3·6 mm. in diameter. At the upper end, by which it is attached to the supporting bracket, the wire is tapered, the length of the cone being 35 mm. to 40 mm., reducing the diameter to 2 mm. The taper is not continued to the extreme end, the last 10 mm. of the wire being left cylindrical. A brass nipple, screwed on the outside for location in the support, is pressed on this portion, so that the wire is attached by the thinnest possible section. A flat, 1 mm. to 1·5 mm. wide, is filed on the side of the cone. These details of shape and size have been arrived at empirically during many years' experience of manufacture, and perhaps the most striking result of the present investigation is its confirmation of their importance, and of the marked effect of even small departures from the specified dimensions. It may be noted, incidentally, that for economy of space the gongs are often bent into the form of flat spirals, but this appears to make little difference to their acoustic properties. The gong is set into vibration by a blow, close to the point of support, from a metal hammer faced with leather or felt.

The investigation began with an examination of a number of gongs, all produced under apparently identical conditions in the same works, but presenting various degrees of tonal quality, some giving the desired clear, long-lasting note, and others a harsh, muffled or short-lived sound. In order to obtain an objective comparison of the behaviour of these gongs, oscillograms were taken by projecting on to a moving photographic film the optical image of a thin wire attached to the free end of the vibrating gong. Four typical vibration records are reproduced in Fig. 1, in which A and B refer to gongs emitting a satisfactory sound, and C and D to inferior gongs. For the non-expert it is not easy to recognise the distinctive features of the two pairs of records, but, according to the authors, the successive changes in amplitude are more abrupt in the unsatisfactory gongs than in A and B. The graphs of good gongs are further characterised by the presence of well-defined overtones in the region of audio-frequency. These are often missing from inferior gongs. When the third overtone is particularly marked in the vibration record, the note is generally good and clear. The facing material of the hammer has an influence in this respect—a single layer of leather gives the best results.

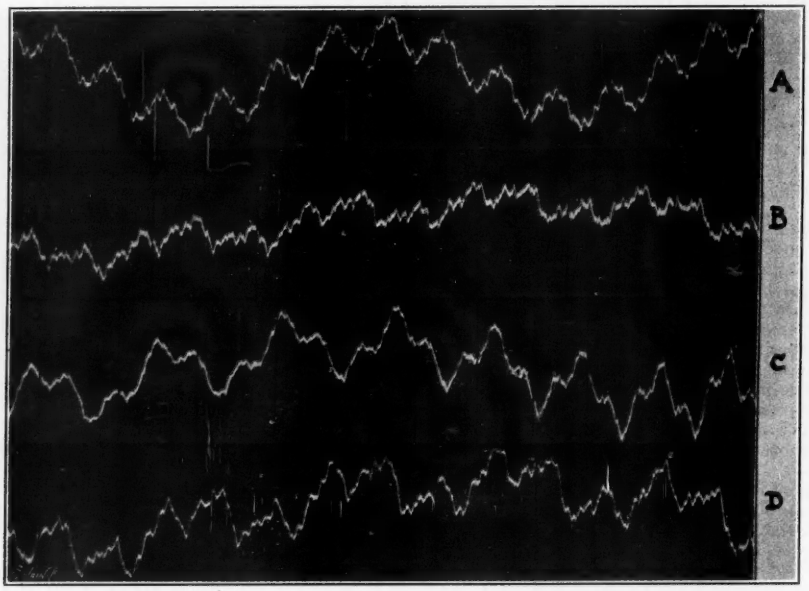

FIG. 1—*Vibration Records of Gongs.*

A and B—Satisfactory. C and D—Unsatisfactory. Vertical Ordinates represent intervals of $^1/_{50}$ second.

All the gongs taken for examination were found to be made from hyper-eutectoid steel containing from 0·9 to 1·1 per cent. carbon, with occasionally very small amounts of chromium and tungsten. In nine such specimens the elastic limits varied from 61·7 kilos. to 85·2 kilos. per square millimetre, the tensile strengths from 79·0 kilos. to 107·5 kilos, per square millimetre, and the Rockwell C hardness from 28·0 to 34·5. It was clear, however, that there was no correlation between the acoustic qualities of the

* Anton Pomp and Burghard Zapp, Beitrag zur akustichen Werkstoffuntersuchung von Stahlstäben, insbesondere für die Herstellung von Gongspielen. Mitteilung aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Dusseldorf. Band XV., Lieferung 3, Abhandlung 220.

gongs and the composition or mechanical properties of the steel.

An examination of the microstructures gave the strongest indication of a connection between the condition of the steel and its suitability for use in gongs. The best results were obtained when the microstructure was very fine, with spheroidised cementite. Coarser grain size, and especially the presence of angular or lamellar cementite, had a definitely adverse effect on the tone.

Equal in importance to the purity of the note is its persistence. When the duration of the note was judged by the unaided ear it was found that an accuracy of ± 5 per cent. could be attained. A refinement of method, using a microphone and observing the fluctuations in e.m.f., gave little advantage as a basis of comparison, owing to the fact that the curve of loudness against time is logarithmic, and becomes asymptotic to the time axis.

The analysis of the effect of external influences on the duration of the note endorsed in a striking manner, as has already been mentiond, the procedure normally adopted in manufacture. Thus, it was found that improvement accompanied increase of the length of the cone at the suspended end of the gong up to 20 mm., but that beyond 20 mm. there was no further change. Similarly, the best value of the maximum reduction in cross-sectional area in the cone was found by analysis to be between 70 and 86 per cent.; in standard practice the reduction is approximately 75 per cent. Experiment also showed that increasing the area of the flat surface filed on the side of the conical end caused a progressive improvement of the note, until the point was reached at which the section of the wire became so small that a blow caused rattling or jangling. A smooth finish on this flat was found to be essential. Within practical limits the duration of audibility was independent of the force of the blow from the hammer. In specimens giving equally pure notes, the duration increased almost in linear proportion to the length of the wire, but gongs of the same length fell in the same order of merit, whether judged by the quality or the duration of the note.

The study of internal influences took into account the heat treatment of the steel, tempering of the finished gongs, the wire-drawing operation, and the carbon content.

In order to amplify the earlier observation of a relation between micro-structure and acoustic properties, the effect of various heat treatments was investigated in gongs made from steels containing 0·29, 0·63, and 1·1 per cent. carbon, the second of these containing also 0·2 per cent. vanadium. Two batches of the rolled wire of the 0·29 per cent. carbon steel were drawn from 5·5 mm. to 5 mm. and 4 mm. diameter respectively. One coil of each was annealed at 680 deg. Cent. and one at 750 deg. Cent., and both were finally drawn to 3·6 mm. diameter, giving final reductions of cross-sectional area of 19 and 48 per cent. Gongs made from these wires were tempered for 15 min. at 300 deg. Cent. Microscopic examination showed that the 680 deg. Cent. treatment produced a structure consisting of cementite finely divided and uniformly distributed through the ferrite. Annealing at 750 deg. Cent. gave irregularly disseminated pearlite, only partially spheroidised. The results of mechanical and acoustic tests are given in Table I. From this it is seen that the spheroidised micro-structure was associated with a longer note duration. A larger degree of final cold drawing was also beneficial in this respect.

In the case of the higher carbon steels, containing 0·63 and 1·1 per cent. carbon, the 5 mm. diameter rolled wire was annealed and drawn to 4·5 mm. diameter. In both materials a further annealing for 2 hours at 900 deg., 760 deg., or 680 deg. Cent. was applied, and in the 1·1 per cent. carbon steel other samples were annealed at lower temperatures down to 500 deg. Cent., in order to produce the fine structures and high strengths encountered in satisfactory commercial gongs. Finally, all samples were cold drawn to 3·6 mm. diameter, this operation giving a reduction in area of 36 per cent. After making into gongs the wires were tempered at 300 deg. Cent. for 15 min. The results of tests on these series of samples are reproduced in Table II. The greatest persistence of note was found in the 1·1 per cent. carbon steel annealed at 500 deg. and 550 deg. Cent.; the strength was also at a maximum in these wires, although the spheroidised cementite particles were not particularly fine. For corresponding heat treatments the 1·1 per cent. carbon steel did not give a longer note than that containing 0·63 per cent. carbon, but it was observed that the former had a distinctly fuller tone. Other experiments on the high-carbon steel comprised quenching in oil from 830 deg. Cent., followed by annealing at 600 deg., 650 deg., and 700 deg. Cent., with a final cold drawing to give 36 per cent. reduction in area. Although these treatments produced very fine structures and high tensile strengths (124·5 kilos., 112·5 kilos., and 105·6 kilos. per square millimetre), no advantage accrued as regards duration of note. A "patented" 0·63 per cent. carbon steel

TABLE I.

Annealing temp., deg. Cent.	Final red'n in area, per cent.	Yield point. Kg. sq. mm.	Max. stress. Kg. sq. mm.	Microstructure.	Duration of note, sec.
a 680	48	62·0	74·7	Spheroidised cementite uniformly distributed	—
b 680	48	70·8	75·2		15
a 680	19	50·0	59·8	" " "	—
b 680	19	58·9	64·8		13
a 750	48	66·0	72·8	Pearlitic islands	—
b 750	48	68·0	73·9		10
a 750	19	55·8	62·7		—
b 750	19	58·8	64·6	" "	6·5

a, not tempered.
b, tempered 15 min. at 300 deg. Cent.

wire, with a sorbitic micro-structure, cold drawn to a reduction in area of 57 per cent., gave the very high strength of 169 kilos. per square millimetre after tempering, but the duration of note was no better than that obtained from spheroidised material of lower tensile strength. Similarly another sample of 0·63 per cent. carbon rolled steel wire, annealed at 640 deg. Cent. and cold drawn directly to give 57 per cent. reduction in area, had a tensile strength of 115 kilos. per square millimetre, but a note duration of only 18 sec. The micro-structure consisted of pearlite and ferrite.

From this part of the investigation it was concluded that in considering the effect of heat treatment of the steel on the acoustic properties, it was the type of micro-structure produced which had by far the greatest influence, and that the mechanical strength attained was of much less significance.

TABLE II.

0·63 per cent. carbon.				1·1 per cent. carbon.			
Annealing temp., deg. Cent.	Yield point, Kg. sq. mm.	Max. stress. Kg. sq. mm.	Duration of note, sec.	Annealing temp., deg. Cent.	Yield point. Kg. sq. mm.	Max. stress. Kg. sq. mm.	Duration of note, sec.
900 *a*	64·0	87·5	—	900 *a*	69·5	86·0	—
900 *b*	78·0	89·5	16·5	900 *b*	79·0	86·0	16
760 *a*	58·5	75·0	—	760 *a*	67·0	83·5	—
760 *b*	71·5	77·5	17	760 *b*	78·0	83·5	17·5
680 *a*	57·5	71·5	—	680 *a*	66·5	81·5	—
680 *b*	64·5	73·6	20	680 *b*	76·8	83·5	20
				650 *a*	79·8	89·0	—
				650 *b*	94·2	96·7	19·5
				600 *a*	81·0	92·8	—
				600 *b*	96·7	100·0	20
Patented *a*	—	—		550 *a*	88·5	98·8	—
Patented *b*	195·0	169·0	19	550 *b*	102·0	104·0	23
Rolled wire *a*	88·5	115·0	—	500 *a*	90·5	103·5	—
Rolled wire *b*	112·0	115·0	18·5	500 *b*	105·0	107·5	23

a, not tempered.
b, tempered 15 min. at 300 deg. Cent.

High Strength Light Alloy Rivets.

AT the present time increasing attention is being paid to light metal structures, and one of the problems confronted by designers and structural engineers is to secure satisfactory joints in high strength light alloys of aluminium. While welding of commercially pure aluminium has now attained the position of being widely used industrially, the welding of the high-strength aluminium-rich alloys is a matter of much greater difficulty. In addition to the initial difficulty in making good welds in such alloys, there are others, probably not fully realised by those technologists who have not had personal experience in this field. For instance, even when heat treatment of welded structures subsequent to welding is a practical possibility, and when the distortion which must inevitably result in some degree is not such as to render the structures unusable, the material at the weld is usually of appreciably lower mechanical strength and corrosion resistance than the rest of the structure. In parts not heat treated after welding, the properties of the material in the vicinity of the weld are usually still less satisfactory. While the results of recent research work on welding of aluminium-rich alloys appear to promise distinct advances in regard to welding in the light alloy world, riveting has to be employed where long joints, and, in fact, many others, have to be made. Several recently published papers on aluminium alloy rivets contain information of special interest and are worthy of careful consideration by those who are concerned with light metal construction.

In aircraft, joints in highly stressed Duralumin structures are frequently exposed, under their normal conditions of use, to corrosive influences. Joints in light alloy floats of seaplanes and hulls of flying boats are exposed to marine conditions, and corrosion is liable to occur in them. G. W. Akimoff (*Korrosion und Metallschutz*, December, 1932, Vol. 8, No. 12, pages 309–313) has examined the causes of rapid breakdown of joints with the object of determining the best materials for combination as rivets and sheets in order to obtain within the ordinary limits of composition of duralumin a minimum of corrosion in joints.

The composition and working of the rivets can be varied to some degree and the relative electrode potentials of rivets and sheet varied correspondingly. In the presence of an electrolyte or moisture, electro-chemical effects may occur between the two electrodes of the combination. Corrosion at such places is a complicated case of contact corrosion, the processes of disintegration by reason of micro-elements in the structure being intensified by electro-chemical effects between sheet and rivets. The compound $CuAl_2$ has a potential strongly electro-positive to that of the aluminium-rich solid solution which forms the main bulk of the duralumin alloys. From this it is seen that inclusions of $CuAl_2$ in duralumin will act strongly as cathodes, and the aluminium-rich solid solution as anode will be attacked when corrosion occurs. The influence of $CuAl_2$ in weakening the protective effect of surface films of hydroxide formed in the early stages of corrosion is also of some import-

ance here. Of the elements normally present in duralumin, copper is the one having the greatest effect on the potential of duralumin. Alloys containing up to 4·6 per cent. of copper form solid solutions on heating, and these may be retained by quenching, but the percentage of copper in duralumin may vary from 2·5 to 5·5 per cent. Quenched duralumin with a considerable amount of copper in solid solution has a higher potential than annealed material in which copper occurs mostly as $CuAl_2$ crystals.

In quenched duralumin the copper is not completely in solid solution, since some $CuAl_2$ is apparrently deposited along with magnesium silicide Mg_2Si in the ageing process, in the form of sub-microscopic particles. Akimoff describes a series of tests on samples of duralumin rivet wire containing 0·5 to 0·7 per cent. of magnesium, 0·3 to 0·6 per cent. of manganese, 0·2 to 0·3 per cent. of silicon, 0·2 to 0·3 per cent. of iron in each case, but with copper content varying in the range 1·8 to 4·9 per cent. The specimens were all in the finally heat-treated (500 deg. Cent.), water-quenched, and fully aged (at least seven days) condition. The samples were subjected to corrosion tests, the results obtained being as follow :—

	Copper content	Loss in weight in 3% NaCl solution after 200 hours, mg./cm.²	Loss in weight in 3%NaCl+0·1% HCl+0·5% H_2O_2 solution after 25 hours, mg./cm.²
I.	1·84	0·68	14·08
II.	2·45	0·68	14·11
III.	2·9	0·48	15·40
IV.	3·45	0·74	14·69
V.	3·8	0·48	14·13
VI.	4·9	0·48	14·40

Considering the above results in relation to isolated duralumin rivets (not in contact with sheet), Akimoff concludes :—

(1) Quenching of duralumin reduces the corrosion considerably, since the number of $CuAl_2$ particles is reduced and the potential of the groundmass of the alloy (AlCu solid solution) is raised.

(2) The difference in copper content of duralumin rivets in the quenched and aged condition has only a slight influence on the corrosion resistance ; a higher degree of corrosion occurs with copper content of 3 to 3·5 per cent.

While the bearing of the experiments described upon the first conclusion is obscure, the work of other investigators and of users of duralumin is in general agreement. In his next experiments Akimoff investigated the current flowing between pieces of the rivet wires and duralumin sheet immersed in corroding solutions and short circuited. The weight losses of both plate and wire were observed. In the first series of contact experiments the corroding agent was 3 per cent. sodium chloride solution, and the current density was measured at frequent intervals during the 100 hours' test. In all cases the current increased with time, after the first few hours. After a few hours, the alloy VI., containing 4·9 per cent. of copper, became cathodic to the duralumin sheet, and afterwards remained so to the end of the test. All the other alloys, I. to V., containing 1·84 to 3·8 per cent. of copper, were anodic to the duralumin sheet throughout. The loss in weight of the wires containing 3·8 and 4·9 per cent. of copper respectively, was lower than that of the others.

In a further series of similar experiments the corroding medium employed was 3 per cent. sodium chloride solution with an addition of 0·1 per cent. of hydrogen peroxide, this series being intended to serve as a confirmation of the first series of contact experiments, and also as an indication of behaviour under more severe conditions (higher rate of depolarisation), or over a longer period. The results obtained fully confirm those of the earlier series. All the wires were anodic to the duralumin sheet material, except those containing 4·9 and 3·8 per cent. of copper, and the loss in weight of these samples was smaller than that of the other wire samples. The sheets of duralumin in contact with these samples suffered greater loss in weight than those in contact with the wires of lower content, the actual results being as follow :—

Wire No.	Copper, per cent.	Loss in weight of wire, mg./cm.²	Loss in weight of sheet, mg./cm.²
I.	1·84	2·48	1·02
II.	2·45	2·80	1·17
III.	2·9	2·32	1·14
IV.	3·45	2·10	—
V.	3·8	1·40	1·88
VI.	4·9	1·46	1·84

The electrode potentials of the alloys of wires I. to VI., measured in the 3 per cent. sodium chloride, 0·1 per cent. hydrogen peroxide solution varied from −0·56 volt for the 1·84 per cent. copper alloy to −0·51 volt for the 4·9 per cent. copper alloy. These experiments show that with copper content of the sheet between 3·7 and 4·9 per cent., rivets with less than 3·8 per cent. of copper act as anodes in the sheet-rivet combination, and rivets with more than 3·8 per cent. of copper act as cathodes. With identical external conditions, *i.e.*, composition of electrolyte, access of oxygen, material of the same composition and condition of heat treatment cannot form a galvanic couple. In practice it is impossible to obtain precisely the same material and condition in rivets and sheet. Assuming a difference between rivet and sheet, the desired polarity can be obtained by the use of the correct copper content in rivet and sheet materials respectively.

The total corrosion (*i.e.*, the number of ions of the anode material going into solution) in the case of corrosion with oxygen depolarisation, *e.g.*, in salt solution, is independent of the anode area in the contact system concerned, and is directly proportional to the cathode area. Assuming the rivet to be the negative pole and the sheet the positive, a relatively large area of sheet will affect a relatively small area of rivet and the total corrosion, which is dependent upon the area of cathode surface, *i.e.*, of the sheet, will be great and concentrated upon a small area of rivet surface. In a few words, there is rapid attack upon the rivets. If, however, the rivet is the cathode and the sheet the anode, the total corrosion is much less, since the cathode (rivet) surface is smaller and the corrosion is consequently spread over a very large area, so that the relative loss of metal per unit of surface is very much smaller. The increase in corrosion of the sheet material as a result of contact with the rivets is practically negligible since the sheet surface is usually hundreds of times greater than the rivet surface. In order to minimise corrosion, it is necessary to choose compositions such that the rivets are more electro-positive than the sheets, and serve

as cathodes. In order to attain this position, the copper content of the rivets must be increased. In existing structures the sheets usually have higher copper content than the rivets. On that account the rivets are strongly attacked under the influence of severely corrosive conditions, such as marine exposure.

The solubility of copper in quenched aluminium-copper alloys is about 5·6 per cent. In duralumin other elements are present as well as copper, and complicate the processes of quenching and ageing. In practice the maximum permissible content of copper is about 5 per cent. According to Bosshard, the strength properties of duralumin are then increased by about 5 per cent.

The work of Shoulgin shows that on the ground of shear strength the copper content of rivets may usefully be increased to 4·5 per cent. Akimoff considers that the copper content of rivets should be 4·2 to 4·8 per cent., and that of sheets 3·6 to 4·2 per cent. for structures exposed to corrosive conditions.

Akimoff does not refer to structures in which the plating or sheet material is other than duralumin. It is now customary in this country and elsewhere to employ Alclad sheets for the construction of floats of seaplanes and for the hull plating of flying boats. M G 7 alloy is also being used for the same purpose. The results of experience with duralumin rivets in both the above materials are in accord with consideration of their electrode potentials, since the rivets are not normally attacked at all. Such experience affords practical support to Akimoff's contention that in duralumin structures the composition of the rivets should be adjusted so that under corrosive conditions the rivets act as cathodes and would appear fully to justify developments in that direction. Akimoff's paper therefore forms a valuable contribution to the technology of light alloy riveting.

Another interesting communication is that of M. Abraham, of the Deutsche Versuchanstalt für Luftfahrt (*Zeits. für Metallkunde*, September, 1933, pages 203–206), dealing with the influence of repeated hardening of duralumin rivets and the temperature of age hardening. It is well known that duralumin rivets can only be used satisfactorily for riveting during a short period following final heat treatment and quenching. In Germany they are generally used only within four hours of heat treatment, but in one American works they are used within 30 min. Of each batch heat-treated, some usually remain behind unused, and these require re-heat treatment. It may happen that particular rivets are heat-treated many times. Some works consider that duralumin rivets age-harden the more quickly the oftener they have been heat treated previously, and that the interruption of age hardening by a new heat treatment is harmful. In some cases rivets which have not been used within four hours are set aside to age-harden fully, this being effected by labelling them Monday's rivets, Tuesday's rivets, &c., and not using them before the same day of the following week.

In some cases the finally heat-treated rivets are placed in solid carbon dioxide (dry ice) at temperatures down to −40 deg. Cent., and used within two weeks of being heat treated. Storing in ordinary ice also delays age hardening considerably, the rivets then being usable for at least 24 hours.

Abraham has investigated the effects of repeated heat treatment and of interruption of age hardening by re-heat treatment. Meissner (D.V.L. Report, Kf 6/4, 14.7.27) had previously investigated the re-heat treatment of duralumin 681B sheets with full age hardening between consecutive heat treatments. After twenty-five repetitions of heat treatment and five days' ageing after each, the same Brinell hardness was obtained. Meissner observed only the final hardness and not the course of the increase in hardness, a matter of importance from the practical point of view. Abraham studied age hardening of rivet wire in duralumin 681A by means of shear tests. Repeated heat treatment followed in each case by full ageing periods (five days) was found to be without appreciable effect on the course of age hardening. After twenty-four hours the shear strength was 28·6 to 29·4 kilos. per square millimetre, and after five days 29·4 to 30·1 kilos. per square millimetre in all cases. The ageing temperatures varied from 24 deg. to 33 deg. Cent., and the lower shear strengths corresponding to the lower ageing temperatures; the higher shear strengths to the higher ageing temperatures.

When ageing was interrupted by re-heat treatment the material age hardened faster than if it had fully aged previously, but the difference in shear strength compared with fully aged material re-heat treated was in no case greater than 2·5 kilos. per square millimetre.

Further investigation of the effect of ageing temperature by ageing heat-treated rivets at 0 deg., 15 deg., 22 deg., 28 deg., and 35 deg. Cent. showed that ageing temperature influences the rate of increase in strength much more than previous heat treatments. Wire aged at 35 deg. Cent. has almost completely regained its original strength after eight hours. The results obtained were confirmed by further tests on actual rivets, and satisfactory agreement observed. A series of tests on wire in the stronger alloy duralumin 681ZB showed similar influence of ageing-temperature after final heat treatment. Abraham points out the very appreciable differences in rate of hardening which must result from differences between summer and winter temperatures in works in which the rivets are allowed to age at room temperature.

Practical riveting tests of ZB alloy wire aged at 35 deg. Cent. showed that the workability only remained satisfactory up to half an hour, but in material aged at 0 deg. Cent. up to 50 hours.

Abraham suggests, with justification, that when rivets are quenched only once a day, and it is desired that they should remain workable for 10 hours, it will suffice to let them stand at a temperature of 8 deg. Cent. Such a temperature may be obtained with a relatively small amount of ice and maintained easily, even in hot weather in the works. The provision of costly ice chests or of solid carbon dioxide for cold storage of rivets appears quite unnecessary.

Books and Publications.

The Book of Stainless Steels. By ERNEST E. THUM. American Society for Steel Treating, Cleveland, Ohio.

THE subject of stainless steels and the associated acid and heat-resisting alloys has developed rapidly during the last two decades, and the applications of these materials for industrial purposes have now become so numerous and varied that a complete treatment of the subject demands wide experience and much specialised knowledge.

In the "Book of Stainless Steels" such a full

treatment is attempted. In estimating the value of the work one has to consider, on the one hand, the matter presented, and, on the other, the manner of presentation. Briefly, it may be said that for the most part the matter presented is of a high order, but that the manner of presentation leaves something to be desired.

The book consists of 600 pages of information collected from authorities in the various branches, and a great deal of specialised practical and useful information, as well as theoretical data, is given. Instead, however, of a gradually developed theme, such as one finds in the well-known publications on this subject, which would provide for an orderly and pleasurable appreciation of the various aspects of the matters discussed, the book takes the form of a series of separately written articles, with insufficient continuity between one and the other, making a study of the subject as a whole rather difficult.

This result naturally arises from the fact that the work is not that of a single author, but of seventy-five authors, and whilst each has dealt on the whole quite faithfully with his selected portion of the subject, and whilst there has clearly been an attempt by the compiler to give an orderly arrangement, the general result approaches somewhat to that of a verbatim report of a long-drawn-out discussion of a meeting of a large technical society. The contributors are in the main specialists in their own branch. The names of Krivobok, Feild, Newell, Grossman, Bain, and Speller, to mention only a few, are sufficiently known in this country to command respect.

The book is divided into three parts :—Production and Fabrication ; Properties of Typical Alloys ; and Requirements of Consuming Industries.

The first section includes sub-sections on steel-making, foundry practice, rolling operations, tube production, machining, welding, and other fabricating processes, each process being dealt with from the practical standpoint, although the views of the different writers are not always concordant with each other nor with British practice. For example, the heating of slabs of chromium-nickel stainless steel, 2½in. thick, for rolling into sheets is given as 1800–1900 deg. Fah., whilst the heating of slabs for plate rolling is given as 2250 deg. Fah.

The notes on steel melting are somewhat sketchy, but those on the later fabricating, such as flanging and dishing, sheet metal working, cold upsetting and descaling processes contain useful practical hints. The notes on machining deal largely and unnecessarily with machining in general, whilst those on welding operations are more specially useful.

A valuable and fundamental chapter in the book is that on the " Constitution of Chromium and Chromium-Nickel Steels," by V. N. Krivobok, but, curiously, this is given in the " Production " section, whereas its proper place would have been Part II. One cannot here discuss the details of this portion of the subject, but the effects on constitution, response to treatment, and properties of the steels containing various combinations of chromium, nickel and carbon are well surveyed. However, some of the data given in the equilibrium diagrams should only be accepted tentatively, as these are matters demanding further investigation, although the principles involved are established.

Whilst Part II. deals with " Properties," Part I. does not omit some mechanical and other test data, particularly the sections on rolling to sheet and strip and drawing to wire. Reference is made in the latter to " wire rope fabricated of 18/8, drawn to 275,000/300,000 lb. per square inch," " excellent for marine and aircraft purposes." Whilst such a production is a possibility, it would be unwise readily to accept the verdict of " excellent." Experience in this country restricts the tensile strength to appreciably lower values in the interests of safety, since the highest tensile strength is only obtained at the risk of danger from stress cracking.

Space is found for notes on " Chrome Plating " and for a section on " Bi-metal Sheets." The latter product consists of ordinary steel with which a thin surface coating of special steel has been combined, and should theoretically permit great economies. How far this is reflected in commercial production is not indicated. It seems probable that the economies are not sufficiently definite or realisable in practice.

The review of " properties of typical alloys " in Part II. is comprehensive as regards mechanical and corrosion resistance data of the main types of stainless steels. Starting with 5 per cent. chromium steel (the reason for inclusion of which is explained on the grounds of heat resistance), the stainless steels and irons (11/14 per cent. chromium) and the higher chromium steels, with and without minor additions of other elements, are dealt with. A special sub-section deals with " Bank Vault " analysis (15/16 per cent. chromium), but it is not clear why this should not have been included in the later section on Chromium Ferrites (16/20 per cent. chromium). As regards Cutlery Stainless Steels, the British and so-called " American " types (containing higher chromium and higher carbon) are compared, and typical hardness and corrosion-resisting data given. The high chromium type of steel used for certain tools (17/18 per cent. chromium over 1 per cent. carbon) is also included as a type of " forging " stainless steel, and still higher carbon-chromium steels up to 2·35 per cent. carbon, as used for gauges, dies, &c., with or without small additions of other elements, are included in the " stainless series."

The higher chromium steels, including 25/30 per cent. chromium iron alloys, have their advantages and disadvantages indicated, with notes on modifications made by the introduction of small quantities of nickel and other elements.

The austenitic chromium-nickel steels, based on the 18/8 chromium-nickel composition, are quite rightly given special prominence, as it is no secret that the development of this class of steel has given great impetus to the commercial exploitation of stainless steels in general, owing to its improved corrosion-resisting properties and adaptability for fabrication processes. A special section deals with Intergrannular Corrosion, a phenomenon which has caused much scientific labour, but is now happily sufficiently understood and controlled to be no longer a cause for anxiety in the hands of those who appreciate the facts. The importance of this subject is unquestioned. At the same time, the repeated references to it by different writers in different sections of the book are apt to be rather laboured, and involve much repetition. The index indicates over twenty references to this matter. So far as the facts are concerned, the behaviour of the different alloys and effectiveness of different means of avoiding trouble are faithfully portrayed, although some of the theoretical discussion is perhaps unduly dogmatic.

The question of material for service at elevated temperatures which is dealt with in various sections naturally arises in connection with a number of different industries, varying in the severity of working conditions. The 5 per cent. chromium steel, with or

without small additions of molybdenum or tungsten, appears to be popular for oil cracking tubes, although better service has been obtained from steels of the 18/8 class. The importance of high temperature strength, absence of appreciable "creep" over long periods, as well as "scale resistance" at high temperatures, are dealt with. A useful survey of valve steels and of heat-resisting steels and alloys for electrical resistors and other very high temperature work is given, including alloys of the Nichrome type. The claims of nickel-manganese austenitic steels and of the cobalt-containing alloy "Stellite" are also described.

In Part III. the book, under the heading of "Industrial Requirements," has special sections on corrosion testing, tests for resistance to scaling, creep testing and endurance testing, and then deals separately with a number of the industrial applications in which the various steels are employed. These include chemical and food industries, paper, dyeing, dairy and brewing, smelting, and special engineering work, such as automobile, aircraft, steam plant marine work, and general architectural work.

The book is well printed, and the illustrations are a good feature.

References to the sources of information are freely given, although the practice in this respect varies very much with the writers of the different sections.

A brief historical and introductory section is given, tracing the development of other alloys from the original cutlery quality stainless steel, discovered by Brearley, the chromium-nickel steel patents of Krupps, the alloys containing silicon, and the higher heat-resisting alloys. It does not appear to be recognised that the basic composition of the 18/8 steels was a British development, since the original Krupp steel was 22/5 per cent. chromium-nickel. This change is of more fundamental importance than might appear at first sight, and the production of this material in America definitely followed the development in this country. There are other directions in which more credit might have been given to British work, although recognition of Mr. Monypenny's book on Stainless Steels is not stinted.

As would be expected, such a book is not possible without the appearance of typically American expressions, but the reference to "bugs" (a machining term) on page 95 is particularly objectionable. As a reference book, the "Book of Stainless Steels" will have an important place in technical literature.

Metallurgical Analysis by the Spectrograph. By D. M. SMITH, A.R.C.S., B.Sc., D.I.C. London: British Non-Ferrous Metals Research Association, 1933. Pp. 114+xi., with 10 plates and 8 figures in the text. 10s. 6d.

IN a Foreword to this monograph Dr. Brownsdon draws attention to the utility of spectrographic as a substitute for chemical methods in the qualitative analysis of metallurgical products. When small impurities have to be detected or when the presence of impurities would affect the quantitative estimation of another important ingredient, the obvious procedure is to make a preliminary qualitative analysis. But qualitative analysis by chemical means usually involves in such cases little less trouble than the complete assay. Hence much time and labour will be saved if a spectrogram can be obtained which will show in a few minutes the nature and the order of concentration of all the metallic constituents.

While, however, the average chemist will acknowledge the probable value of the spectrograph for qualitative work, he is often deterred on three grounds from incurring the fairly serious expense of purchasing a suitable instrument:—(1) The technique of spectrography is somewhat foreign to his experience; (2) the spectrograms that he sees contain such a multiplicity of lines as to make him somewhat nervous of their interpretation; (3) he is convinced that no results of a strictly quantitative nature are obtainable by this method.

For the last eight years the British Non-ferrous Metals Research Association has studied the application of the spectrograph to the quantitative analysis of non-ferrous metals and alloys, and this book is designed to encourage the more general adoption of spectrographic tests in metallurgical chemical laboratories. Mr. Smith has been directly engaged in these investigations, and he has here provided answers to the three objections above raised. He describes (Chapters I. and II.) the principles of the spectrograph and the general procedure for its use. In Chapter III. he shows how, by reference to tables of sensitive lines, one may ignore the presence of hundreds of lines that are of no analytical interest, and may verify with the required accuracy the wavelengths of those lines whose occurrence establishes the identity of various constituents. The remainder of the book is concerned entirely with quantitative work. Chapters IV. and V. deal with the questions, vitally important in this connection, of standardisation of technique in the production of the arc or spark source of light, and in the photography of the spectrum. The quantitative comparison of line intensities is considered in Chapter VI., a full account being given of Gerlach's "internal standard" method. This allows the experience of one laboratory in the correlation of line intensities with the composition of the electrodes to become available to other workers, who do not then need to prepare a series of standard samples of known composition. Detailed tables are given (Chapters VII. and VIII.) of "homologous pairs" determined by the author, which are intended to allow fairly close estimates of impurity contents to be obtained from spectrograms furnished, under specified conditions, by samples of zinc, tin, lead, and copper submitted for assay in any laboratory that is equipped with a quartz spectrograph. The concentrations listed vary from as low as 0·0001 per cent. in some cases to as high as 3 per cent. in others.

Time will show whether the author has been unduly optimistic as to the precision with which other workers will be able to reproduce the conditions essential for the correct application of his tables without the use of analysed standard samples. He has, at any rate, presented examples which demonstrate that it is possible in one laboratory to secure an accuracy closer than ± 10 per cent. in the estimation of constituents occurring in concentrations not exceeding 3 per cent.

The Association is to be congratulated on its policy of sponsoring the investigations that have been summarised here. Its action in publishing Mr. Smith's account of the principles involved and of the results obtained should do much to popularise the application of spectrographic methods to metallurgical analysis. The book is well produced and printed, and the illustrations are apt and clear (but the last of the folding plates is upside down). An excellent bibliography with 114 entries is provided in lieu of an author index.